Powerful Products for the Enhanced Flexibility of Gas Turbines

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Content

Abstract .................................................................................................................. 3
Introduction ............................................................................................................ 4
Enhanced flexibility for E-class gas turbines ............................................................ 5
Power Limit Increase ............................................................................................... 6
Wet Compression .................................................................................................... 7
Enhanced flexibility for F-class gas turbines ............................................................ 8
Advanced Stability Margin Controller ................................................................... 9
Advanced Compressor Mass Flow Increase ............................................................. 9
Turn Down .............................................................................................................. 10
Turn Up .................................................................................................................. 11
Wet Compression .................................................................................................... 12
Operational Flexibility Upgrade ............................................................................. 12
Conclusion ............................................................................................................. 13
References ............................................................................................................. 13
Permission for use .................................................................................................. 13
Disclaimer .............................................................................................................. 13

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Abstract

With a steadily growing share of renewable sources of power generation and the ongoing development of competitive electricity and gas markets, the need is emerging for additional flexibility in our advanced gas turbines. The Advanced Compressor Mass Flow Increase and Advanced Stability Margin Controller upgrades provide our customers with the opportunity of additional flexible power and an economical alternative to additional generation equipment.

The Advanced Compressor Mass Flow Increase upgrade is part of the SGT5-4000F (V94.3A) new apparatus design based on the proven SGT5-8000H design. The new 3D compressor blade and vane profile is highly efficient, resulting in a compressor mass flow increase and consequently in a power increase of up to 10 MW for the gas turbine and 14 MW in combined cycle (1x1) operation. The Advanced Compressor Mass Flow Increase upgrade is retrofittable in the SGT5-4000F (V94.3A) service fleet.

The Advanced Stability Margin Controller continuously monitors combustor behavior. The resulting feedback enables automatic engine tuning and automatic engine protection. In addition, the operator is informed about potential issues with the combustion process. For natural gas operation, the pilot gas volume and the turbine outlet temperature are modulated by an automated control logic to prevent the engine from high combustion chamber acceleration events. This supports engine operation with an optimal power output at the lowest combustion dynamics.

Fast de-loading, gas turbine trips, and subsequent combustion-chamber inspections can be avoided by increased combustion stability during part and base load operation.

By implementing the Advanced Compressor Mass Flow increase and/or the Advanced Stability Margin Controller upgrades, gas turbines can remain highly reliable and competitive in the continuously growing F-class market.
Introduction

Gas turbine design and manufacturing technologies have advanced significantly in the years since the first gas turbine VM1 was designed in 1956. More than 14 different gas turbine types have been developed by Siemens since then, reflecting the evolution of the electricity market, changing environmental requirements including stewardship of available fuel resources, and the globalization of the energy market.

The need for peak load and reserve capacity has been continuously increasing in recent years. With a growing quantity of regenerative energy generation (wind, solar) being added to power systems worldwide, the requirement for reserve capacity that can be provided on demand is also increasing. In Germany, for example, installed wind generation capacity accounts for more than 26 GW installed capacity, and significant additional generation is being added through new offshore wind parks. The proportion of the actual energy contribution from wind generation in Germany is typically between five and ten percent of annual energy generation, with generation duration of approximately 18 percent on an annual hourly basis. Clearly, reserve peaking capacity needs to be available on short notice when needed by the power system to support renewable generation. As new projects usually require protracted development periods due to long lead times for site permitting and construction, an appropriate alternative is to increase the capacity of power plants already in existence. [1]

New design and manufacturing technologies – including advances in design and modeling technologies and the refinement of design criteria as well as advances in material, cooling, and coating technologies – have also been used to develop upgrades and component enhancements for the existing fleet. As the original equipment manufacturer (OEM), Siemens has a huge advantage, and continuously introduces technical enhancements within its new unit and service business. The main market drivers for gas turbine modernization within the service business are the following:

- Power output increase
- Efficiency improvement
- Operational flexibility
- Reduction of maintenance efforts
- Emission reduction
- Improvement of reliability and availability

Selected products and technical solutions that enhance the operational flexibility of V-frame gas turbines will be explained in the following sections. These products will improve grid or peak load capacity and part load operation capacity and will expand existing maintenance concepts.

Fig. 1: Development path of V-frame gas turbines
The SGT5-2000E (V94.2) is an extremely well-proven, robust engine for the 50 Hz market and is used for simple or combined cycle processes with or without combined heat and power production in all load ranges, especially in peak-load operation. The SGT5-2000E (V94.2) was introduced in the early 1980s and was installed almost 300 times with its 60 Hz equivalent, the SGT6-2000E (V84.2). Together this fleet has accumulated more than 20,000,000 equivalent operating hours (EOH). Several modernization and upgrade solutions have been developed over the past 30 years reflecting various market needs, for example, the changing requirements for reserve capacity and flexibility.

Siemens' most powerful modernization products for enhancing the E-class gas turbine’s flexibility are the Wet Compression upgrade and the Siemens innovative 3D-optimized (Si3D) turbine efficiency upgrade. With the introduction of the Power Limit Increase to the SGT5-2000E (V94.2), the remarkable advantages of the optimized turbine blades and vanes are used to achieve an even greater increase in capacity.
Our latest development, specially designed for combined heat plants (CHP) as well as for high power applications like Wet Compression, is the Power Limit Increase (PLI), which is based on the Siemens innovative 3D-optimized (Si3D) turbine efficiency upgrade.

With the latest Siemens innovative 3D-optimized turbine blade and vane technology for the mature SGT5-2000E (V94.2) frame, and based on the successful validation test results in the winter of 2012, Siemens is currently preparing the fleet release to expand the current power limit from 173 MW to 185 MW for all SGT5-2000E (V94.2) units equipped with Siemens innovative 3D-optimized turbine stages one to four. However, the unit-specific scope may differ and is subject to a site-specific evaluation. This not only means more power over the entire temperature range, it also means additional output in the temperature range below the current power limit, which was not accessible with gas turbine units of older design phases.

In addition, CHPs are operated primarily in northern countries where the demand for electricity meets an effective way of producing district heating for households or industry. District heating output at low ambient temperatures is limited by the current power limit of the rear stages gas turbine blades. With falling ambient temperatures, power plants with service-exposed SGT5-2000E (V94.2) units are affected in such a way that the closing inlet guide vanes that limit the gas turbine’s power also throttle the district heating output. This forces the power plant operator to provide the extra heat energy required from other resources, which usually operate less efficiently than the CHP. [2]

Compared with the reference case of a SGT5-2000E (V94.2) from an older design stage, an increase of up to four percent of exhaust gas energy can be utilized over a wider ambient temperature range. This huge performance increase helps strengthen power plant operators’ market position.

**Fig. 3: Customer-driven service product development SGT5-2000E (V94.2)**
Wet Compression

The Wet Compression upgrade is a reliable and proven method of injecting water into the gas turbine inlet. Wet Compression is perfectly suited for upgrading peak load gas turbines. Providing peak power enables electricity producers to react to increased grid power demand, for example, during summer peaks or grid fluctuations driven by renewable energy sources, and increases customer revenues at high peak load electricity prices. Wet Compression is designed to increase power output up to 18 MW by injecting water into the compressor inlet, which inter-cools the compressor, reduces the compressor inlet temperature, and increases mass flow throughout the gas turbine.

Wet Compression can be used for various purposes: the most common and commercially attractive ones are:
- Seasonal operation (summer peak operation)
- Reserve power and occasional peaking
- Grid support
- Base load increase for simple cycle gas turbines

The seasonal operation of Wet Compression to compensate for capacity losses during high ambient temperature conditions is possible in both dry and humid areas. Moreover, a combination with an evaporative cooler or chiller is possible as long as the compressor inlet temperature stays above 10° Celsius. Implementing the Wet Compression upgrade to increase the marketable power reserve and for occasional peaking is ideal, because the impact on the normal operation of the gas turbine is very minimal.

Wet Compression was developed in 1995 and redesigned for the SGT5/6-2000E (V84.2 / V94.2) in 2003. More than 45 Wet Compression systems have been installed and operated on Siemens E-class gas turbines since that year.

![Graph: Comparison of Wet Compression power output with an Evaporative Cooler at a variation of relative humidity](image)

**Fig. 4: Comparison of Wet Compression power output with an Evaporative Cooler at a variation of relative humidity**
The proven SGT5-4000F (V94.3A) is characterized by high performance, low power generating costs, and long intervals between major inspections as well as an easy-to-service design. Since 1996 more than 200 units have been installed worldwide. Its 60 Hz equivalent SGT6-4000F (V84.3A) was introduced in 1997 and has been sold more than 50 times since then. Together this fleet has accumulated more than 10,000,000 EOH. The SGT5-4000F (V94.3A) is based on the SGT5-2000E (V94.2) and on proven standard design concepts. With optimized flow, combustion, and cooling systems as well as new materials, a gas turbine efficiency of nearly 40 percent ensures a strong position in a competitive market.

Market requirements have been trending toward fast start-up times, higher load gradients, and peak load capacity. Research predicts the development of market demand in the direction of even higher flexibility required of gas turbine operation modes. Our most powerful modernization and upgrade products that meet the challenges of the changing power generation market and enhance the F-class gas turbine flexibility are the following:

- Advanced Stability Margin Controller (aSMC)
- Advanced Compressor Mass Flow Increase (CMF++)
- Turn Down
- Turn Up
- Wet Compression
- Operational Flexibility Upgrade (OFU)

Enhanced flexibility for F-class gas turbines

![Diagram showing modernization and upgrades for F-class gas turbines]

- Advanced Compressor Mass Flow Increase
- Operational Flexibility Upgrade OFU
- Thermal Performance Upgrade
- Improved Hot Gas Parts
- Burner Upgrade (Low-NOx -> Premix-Pilot)
- Cooling Air Reduced Combustion Chamber
- Burner Upgrade (Reduced Swirl)
- Fuel Gas Preheating
- Compressor Mass Flow Increase
- Turndown
- Hydraulic Clearance Optimization
- HR3 Burner
- Firing Temperature Increase
- 15 Stage Compressor

Additional Modernization & Upgrades

- Advanced Compressor Coating
- EVAP Cooler
- Advanced Stability Margin Controller

Ongoing Development

- Further Firing Temperature Increase
- Grid and Peak Load Products

Power Output

- 208 Units in Commercial Operation 1)  
  Total EOH > 7,734,000  
  Lead Unit EHO > 119,000

- 1996 2)  
  [240 MW; 37.0 %]

- 2003
  SP4

- 2005
  2008

- 2010
  2011

- 292 MW; 39.8 % 4)

1) As of March 2012
2) 17-stage Compressor
3) Since 1998: 15-stage compressor
4) Expected values only, site specific values may vary

Fig. 5: Customer-driven service product development SGT5-4000F (V94.3A)
Advanced Stability Margin Controller

The Advanced Stability Margin Controller increases combustion stability during part and base load operation, allowing more flexible operating conditions in part load and a fast reaction to grid code fluctuations. The combustion dynamic monitoring system continuously monitors combustor dynamic pressure fluctuations to provide feedback for automatic engine tuning, automatic engine protection, and to alert the operator to potential issues with the combustion process.

The combustion tuning potential by pilot-gas variation at low load is limited due to upcoming combustion instabilities and cold or hot spot problematic. An increased pilot gas mass flow reduces the cold spot problem but increases combustion instability. A decreased pilot gas mass flow reduces combustion instability but increases the cold spot problem. Therefore there is only a small range available for pilot gas tuning. Depending on combustion stability, the pilot gas mass flow or the turbine outlet temperature are modulated to achieve a stable combustion. The Advanced Stability Margin Controller provides closed-loop control of the combustion acoustic and the simultaneous evaluation of control parameters, resulting in a real-time adjustment to changing gas quality, ambient conditions, and power output. The Advanced Stability Margin Controller is based on extensive knowledge and experience in gas turbine combustion acoustics. Siemens Energy has extensive experiences with more than three million accumulated EOH worldwide.

Advanced Compressor Mass Flow Increase

This evolutionary component upgrade is based on the well-proven Compressor Mass Flow Increase (CMF+) introduced in 2003. The Advanced Compressor Mass Flow Increase (CMF++) enhances the gas turbine’s power output up to 10 MW, and even up to 14 MW in combined cycle operation (1x1). The established Compressor Mass Flow Increase upgrade is the state-of-the-art in the new apparatus business for the F-class gas turbines and has accumulated more than 1,800,000 EOH since its first introduction in 2003. The Advanced Compressor Mass Flow Increase is its subsequent development and includes an aerodynamic redesign of the first six compressor stages.

It realizes the latest advances: for example, a scoop design of compressor row one. The improvements are based on the SGT5-8000H compressor hardware design. The huge performance increase is realized with no material changes, no changes in flow paths, and with no impact on the EOH accumulation.
**Turn Down**

A growing number of operators are requesting wider ranges for part load operation, with the gas turbines still achieving their emission requirements. With respect to combined cycle power plants, this is constrained by the need to keep the turbine outlet temperature at the high base load level, allowing the steam turbine to be operated at a high efficiency level as possible. The implementation of the Turn Down upgrade is designed to answer the operator’s demand for lower gas turbine part load operation at high combined cycle power plant efficiency levels. After implementing a new linearization unit for the inlet guide vane and a new positioning sensor, the closed position for the inlet guide vane is adjusted to a new set point, which results in an increased power range with low emissions and constant turbine outlet temperatures. The actual minimum part load depends on site-specific conditions and the desired carbon-monoxide emission level. The set point for the minimum part load is usually lower than 40 percent base load.

The Turn Down upgrade is the state-of-the-art for new Siemens gas turbines for the F-class market and may be combined with other modernizations. Since its first application in 2003, more than 100 gas turbines have been in commercial operation worldwide with more than 2,000,000 EOH.
Turn Up

The frequency response capability of combined cycle power plants is generally activated by modulating the gas turbine output. The steam turbine follows the gas turbine’s changes with a physical delay in steam generation. The Turn Up upgrade can be implemented in order to combine the full availability of both the minimum primary and secondary frequency reserve for a high continuous plant output above 100 percent.

Turn Up refers to opening the compressor inlet guide vane beyond its standard design position, with an increase of six degrees toward the open position. This leads to an increased compressor mass flow resulting in an increased gas turbine power output of up to six MW, while the compressor efficiency remains nearly constant.

Due to the fact that Turn Up provides power above base load, operation closer to the maximum efficiency point can be realized while still preserving the entire primary frequency response reserve. Consequently, the gas turbine operates at higher part load. Because the Turn Up upgrade is designed for the optimization of primary frequency response, fast load gradients are applied. The average power output of the plant will increase; a minor increase in average combined cycle efficiency can also be expected.

Fig. 9: Upgrade benefit: gas turbine operation closer to base load
As already described, the Wet Compression upgrade was successfully introduced in the E-class gas turbines and was redesigned for the F-class market to meet their changing requirements regarding plant flexibility and capability. The commissioning of the first application on the advanced frame SGT5-4000F (V94.3A) was successfully accomplished in 2010. The system shows a similar potential as on the SGT5-2000E (V94.2). The highest delta gas turbine power output of about 16 percent has been measured at a Wet Compression mass flow of about 10.2 kg/s. In addition, the gas turbine’s efficiency has been increased by about two percent. The achievable maximum power output of up to 30 MW with Wet Compression is limited by a maximum water mass flow (two percent of the compressor inlet mass flow). However, not all sites can reach the full potential of Wet Compression due to site-specific limitations that include generator/transformer limits, shaft limits, combustion instabilities, and special limiting hardware configurations.  

The Operational Flexibility Upgrade (OFU) is an integration of proven products that optimize the individual power plant performance and increasing operational flexibility within a long-term service agreement. The Operational Flexibility Upgrade combines proven technologies that include improved blade and vane design and enhanced combustion technology.

The Operational Flexibility Upgrade includes a turbine performance upgrade that modifies key turbine components and hot gas parts, allowing for a significant firing temperature increase. This modernization has been designed to generate a power increase, an improvement in heat rate, and additional exhaust energy. These results are achieved through the application of new coatings on the turbine blades and vanes and a reduction in cooling air in the hot gas path. In addition to the performance increase, the Operational Flexibility Upgrade allows for a maintenance interval extension to 33MAC. This results in increased availability of the entire plant, because the major outage is only performed every 33,000 EOH.

The following benefits can be achieved:
- Up to 13 MW gas turbine power output increase in simple cycle operation
- Up to 21 MW combined cycle power output improvement (1x1)
- Up to 0.4 percentage points combined cycle efficiency improvement
- Potential reduction of NOX emission down to 15 ppm

The Operational Flexibility Upgrade optimizes upgrade combinations and provides the best unit-specific balance of plant solutions, with the maximum possible performance increase and enhanced maintenance intervals as part of a long-term program contract extension. The Operational Flexibility Upgrade is the ticket to a flexible operating domain that extends the original equipment manufacturer coverage beyond 100,000 EOH and can be implemented at any outage during the long-term service agreement program. The Operational Flexibility Upgrade will typically be implemented at the 100,000 EOH outage. 
Conclusion

Recent improvements in turbine technology have produced major benefits, including increased flexibility and improved reliability and availability. All of these benefits make a gas turbine modernization project attractive and highly beneficial for aging power plants. In addition, short lead times for the realization of these modernizations and upgrades – when compared with new installation projects – enable a response to near-term capacity needs.

The upgrade solutions described above – the Power Limit Increase, Wet Compression, and Operation Flexibility Upgrade packages, among others – represent only a small part of the solutions provided for the Siemens gas turbine fleet today, and reflect the market’s demand for enhanced capability and flexibility. Many more solutions are available, and they can be combined to address the customer’s need for not only improved flexibility but also high reliability and availability with reasonable maintenance costs and reduced emissions.

Each upgrade step is verified with various test methods to ensure reliable engine operation. The proven product development process and the integrated validation concepts demonstrate an extensive quality assurance model for our customers. As part of this continuous research and development process, Siemens is committed to delivering excellent solutions that are highly beneficial for the power generation industry.

References


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